NASA-CR-194495

Final Technical Report
NASA Grant NAGW-1166

Integration of Space and In-Situ Observations to Study Atmosphere, Ocean and Land Processes

1 September 1987 - 31 August 1992

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A research investigation was conducted into the possibility of using atmospheric observations made in the past from both terrestrial and space-based platforms to create a global, coherent four dimensional analysis for the purpose of studying atmospheric, oceanic and land surface processes relevant to climate simulation, monitoring and change. This investigation consisted of the following tasks:

- A mature global data assimilation system was obtained from the National Meteorological Center and modified for use on a Cray X-MP computer system.
- Atmospheric observations for the period 20 November 1982 through 1 March 1983, including rawinsonde soundings, aircraft-based measurements, pilot balloons, and temperature soundings from polar orbiting satellites were obtained from several sources.
- The global data assimilation system was used to reassimilate the atmospheric observations to produce a new atmospheric analysis which was then compared with the contemporaneous analysis.

The global hydrologic cycle, including fluxes between the atmosphere and both the land and ocean surfaces, was estimated. The flux of water from the ocean surface into the atmosphere, its transport in the form of latent heat to remote regions, and its return to the surface in the form of precipitation were estimated globally. In addition, several regional budgets for selected tropical oceanic and extratropical continental areas have also been done.

The period of 20 November 1982 through 1 March 1983 was chosen because of the high level of ocean-atmosphere interaction during that period. It was found, for example, that much more realistic analyses of the surface temperature analysis over the tropical Pacific Ocean provided a more accurate picture of the ocean-atmosphere interaction during the unusually large El Niño event of that period.

Among the other significant improvements over the contemporaneously produced analysis we found in the reanalyzed data were the more realistic representation of the planetary boundary layer temperatures and winds over the tropical oceans. This improvement allowed a much more accurate calculation of the surface fluxes of latent and sensible heat. Also improved were the mean meridional circulation which provided a much better estimate of the poleward transport of

(NASA-CR-194495) INTEGRATION OF SPACE AND IN-SITU OBSERVATIONS TO STUDY ATMOSPHERE, OCEAN AND LAND PROCESSES Final Technical Report, 1 Sep. 1987 - 31 Aug. 1992 (Maryland Univ.) 11 p

N94-14500

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moisture by the large scale flow. The representation of the humidity field was substantially improved, although this sensitive quantity is one where further research is needed into extracting information from the existing observations and into developing better observing systems for measuring moisture content in the atmosphere and at the land surface. Finally, the assimilating model simulation of the evaporation (ocean surface), evapotranspiration (land surface) and precipitation fields allowed the calculation of a complete moisture budget (Kinter et al., 1989).

A study workshop was organized and hosted by the co-principal investigators in which international experts in data assimilation were assembled to discuss the merit and feasibility of a larger reanalysis effort than was undertaken in this pilot study (Kinter and Shukla, 1989). The consensus of the group was that there is a real need to use modern data assimilation and quality control techniques on the available archive of atmospheric observations to develop a comprehensive, coherent, global analysis for climate monitoring and climate research.

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FINAL REPORT

for

Integration of Space and In Situ Observations to Study Atmosphere, Ocean, Land Processes: Climatic Water Budget Supplement

U.M.C.P Reference: Cooperative Agreement No. 26929B

by

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Project Budget:
$64,283

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Research was conducted concerning the development of a decadal-scale data set containing time series of monthly air temperature (T_m), precipitation (P_m), evapotranspiration (E_m), soil moisture (w_m) and snow cover (w^s_m) for the terrestrial world. This data set was completed and delivered to David Straus at the University of Maryland. It contained the above-mentioned variables for most of the 1970s and 1980s. Time series of T_m and P_m were made available by NCAR. A spatial interpolation procedure discussed by Willmott et al (1985b) as well as a high-resolution climatology of T and P were used to estimate values of T_m and P_m at the nodes of a 0.5°x0.5° lattice. The derived variables (E_m, w_m and w^s_m) were obtained from the gridded T_m and P_m data using the water-budget algorithm described by Willmott et al. (1985a)

Spatial interpolation of climate variables, especially from a sparse station network, has been shown to produce considerable bias both in the estimation of grid-point values and spatial averages (Willmott and Legates, 1991: Willmott et al., 1991). To improve upon the raw station-network-to-grid-point interpolation that is common in the climatological literature, a climatologically Aided Interpolation (CAI) scheme was developed, tested and used to estimate our terrestrial fields of T_m and P_m. This involved computing a difference between a monthly normal at each NCAR station location (obtained from Legates and Willmott's 1990a and 1990b high-resolution climatology of monthly averages) and the actual monthly value of the NCAR observation at that station. Once these differences were obtained for all NCAR months and stations, they were interpolated to the 0.5°x0.5° grid and then added to the Legates and Willmott normal available at that grid node. Illustrating for P_m, a precipitation difference was first computed from

$$dP_i = P_{mi} - P_{ci}$$

where P_{ci} is the climatological normal for that month at station i

(from Legates and Willmott, 1990a) and P_{mi} is the actual monthly precipitation value drawn from the NCAR data set for month m and NCAR station i. NCAR-station precipitation differences (dP_is) then were interpolated to the 0.5°x0.5° lattice (according to Willmott et al., 1985b) to obtain an estimate at each grid point j (dP_j). Each dP_j subsequently was added to the corresponding Legates and Willmott climatological mean at that grid point, which gave an estimate of monthly precipitation at j (P_{mj}). This "new" interpolation scheme has been tested on a variety of data sets (cf, Robeson, 1992) and has been found to be far superior to the simple interpolation from the NCAR stations to virtually any resolution lattice. Papers by Willmott and Legates (1991) and Willmott et al. (1991) report on the sizeable biases that can arise when simple spatial interpolation to a grid is made from a sparse station network. Using Willmott et al.'s (1985a) water-budget procedure, values of E_{mj}, w_{mj} and w^*_{mj} were estimated for all months available in the NCAR archive at the 0.5°x0.5° resolution.

A few tasks remain incomplete. A wind-velocity time series for the terrestrial world was proposed; however, owing to a number of data incompatibilies, the final data set remains to be completed. A "corrected" (for raingage biases) precipitation time-series data set also remains incomplete because the gage-correction procedure requires the wind-velocity fields. Efforts by the Principal Investigator and his colleagues to complete these data archives are ongoing and,. when complete, they will be made available to the climatological community. Upon completion, it also will be possible to compute more accurate E_m, w_m and w^*_m fields.

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Final Report

Project Title:	Interaction of Space & In Situ Observations to Study Atmosphere-Ocean-Land Processes: Climatic Water Budget Supplement
Sponsor:	University of Maryland
PI:	Brian F. Farrell
Institution:	Harvard University Division of Applied Sciences Pierce Hall Harvard University Cambridge, MA 02138
Award Period:	09/01/87 - 08/31/92

Linear Instability and Predictability of Observed 3-d Atmospheric Flows

The two main areas of work were supported by this subcontract: study of the localization of storm tracks and study of the predictability of flow regimes.

Our study of storm tracks involved relaxation of the assumption of flow symmetry. One major effect of asymmetries is the emergence of a correspondence between local instability on jets and absolute instability of the nonlocal jet which potentially restricts storm track instability to a limited subset of flow configurations. We find that local instability requires easterly flow near the ground, that the storm tracks must extend for O(10) Rossby Radii in order to support local instability (DelSole and Farrell, 1993), and that the response of a stable jet to stochastic forcing increases rapidly with shear and decreases with static stability (Farrell and Ioannou, 1993).

The predictability problem was examined building on a new method for identifying disturbances that produce the most rapid growth of perturbation variance (Farrell, 1990). This work addresses the observation that the atmosphere varies in predictability depending on the flow regime. The method developed for studying idealized flows can be extended to NWP models, indeed this is presently being pursued at ECMWF. This extension involves use of the adjoint of the linearized NWP model already developed for applications in data assimilation.

PUBLICATIONS UNDER THIS CONTRACT

DelSole, T., and B. F. Farrell, 1993: Absolute and convective instabilities in a nonlinear two layer quasi-geostrophic model. J. Atmos. Sci., (submitted)

Farrell, B. F., 1990: Small error dynamics and the predictability of atmospheric flows. J. Atmos. Sci., 47, 2409-2416.

Farrell, B. F., and P. J. Ioannou, 1993: Theory of the stochastic dynamics of baroclinic waves. J. Atmos. Sci., (submitted)

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1. STORM TRACKS

The Northern Hemisphere midlatitude troposphere is dominated by a zonal jet concentrated near the tropopause; closer examination reveals that the jet is variable in intensity and orientation forming geographically localized storm tracks associated primarily with the western ocean boundaries. Of central interest to meteorology are the ubiquitous transient waves with scale of a few thousand kilometers which form and propagate on this relatively fixed background flow. The origin and growth to moderate amplitude of these synoptic scale waves is generally ascribed to linear baroclinic instability of the jet. This theory is founded on the discovery that the quasi-geostrophic equations linearized about an inviscid, zonally symmetric, baroclinic basic state support normal modes that grow exponentially in time. These unstable modes have approximately the scale and structure of observed waves and the theory constructed around these instabilities presumes that infinitesimal perturbations to the zonal flow occur with nonzero projection on the modal spectrum so that over many doubling times the wave of maximum growth eventually dominates the observed synoptic scale variance.

Recent work on baroclinic instability theory has involved a relaxation of assumptions made in earlier studies in the interest of simplicity, one of these being neglect of flow asymmetries. One major effect of asymmetries is the emergence of a correspondence between local instability on jets and absolute instability of the nonlocal jet which potentially restricts storm track instability to a limited subset of flow configurations (Pierrehumbert, 1984). In the case of nonzonal flows it is important to separate local instability from global modes which maintain their instability by cycling energy all the way around the globe obtaining a boost on passing repeatedly through the enhanced baroclinicity of the storm track region. It is likely (Pierrehumbert, 1984; DelSole and Farrell, 1993) that the latter are not physically realistic; unfortunately in a nearly inviscid model it is difficult to tell local from global instability so that the nonzonal instability calculations mentioned above do not answer the question of whether realistic observed flows support local instability. We have addressed this problem in two ways, first by constructing a nonlinear q-g channel model with sponge layers at the ends to allow controlled experiments on the absolute/convective transition in zonally asymmetric flows, and second by forcing jets stochastically in a linear model to determine how local response to forcing varies with shear and static stability. We find that local instability requires easterly flow near the ground, that the storm tracks must extend for O(10) Rossby Radii in order to support local instability (DelSole and Farrell, 1993), and that the response of a stable jet to stochastic forcing increases rapidly with shear and decreases with static stability (Farrell and Ioannou, 1993).

2. PREDICTABILITY

The predictability problem was examined building on a new method for identifying disturbances that produce the most rapid growth of perturbation variance (Farrell, 1988, 1989, 1990). This work addresses the observation that the atmosphere varies in predictability depending on the flow regime. The method used involves constructing a spanning set of perturbations ordered in growth of variance over a time interval chosen to be representative of synoptic predictability intervals of around a week. These perturbations define the axes of the predictability error ellipse and the axes of maximum growth determine the predictability of the flow while the form of the perturbations of maximum growth correspond to the preferred responses of the system. A preliminary study of predictability has been carried out for flows chosen to model midlatitude storm tracks.

Having in hand theoretical understanding of the predictability problem puts us in position to apply the theory to observed flows. We expect from experience with model problems that flows with rapid perturbation growth can be distinguished from more predictable flows by differences in evolution of the error ellipse. A new method for obtaining criteria for a given flow to be predictable and by extension those characteristics of flows that are most crucial to observe accurately in order to obtain a good forecast are central results of this study.

The method developed for studying idealized flows can be extended to NWP models, indeed this is presently being pursued at ECMWF. This extension involves use of the adjoint of the linearized NWP model already developed for applications in data assimilation.

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